

World Renewable Energy Congress 2011 – Sweden
8-13 May 2011, Linköping, Sweden

Bioenergy Technology (BE)

Options for Increased Use and Refining of Biomass – the Case of Energy-intensive Industry in Sweden

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Abstract: Events in recent decades have placed climate change at the top of the political agenda. In Sweden, energy-intensive industries are responsible for a large proportion of greenhouse gas emissions and their ability to switch to renewable energy sources could contribute to the transition to a decarbonised economy. This interdisciplinary study has its starting point in three energy-intensive industries' opportunities to take part in the development towards increased refining and use of biomass. The study includes the pulp and paper industry, the iron and steel industry and the oil refining industry, each exemplified by a case company. It can be concluded that there are several technological options in each industry. On the other hand, implementing one option for increased use of biomass in each case company could demand up to 34% of the estimated increase in Swedish biomass supply, in 2020. Additionally, in a longer time perspective none of the case companies believes that the amount of biomass in the Swedish industrial energy system have the possibility to increase significantly in the future.

Keywords: Biomass, Energy-intensive industry, CO₂ emissions, Case study.

1. Introduction

Increased awareness of the effects of climate change has placed mitigation of greenhouse gas emissions at the top of the political agenda, urging a transition to a decarbonised economy. Sweden has taken a prominent position in the international discussions about this transition and is simultaneously creating national policies to mitigate climate change, for example the green certificates for generation of electricity from renewable energy sources. In Sweden, the industrial sector represents one third of the total energy use and in 2008 this sector used 151 TWh [1]. The Swedish pulp and paper, iron and steel and oil refining industry accounted for more than 70% of the energy use (50%, 15%, 7% resp.) in the industrial sector and were responsible for 44% of the CO₂ emissions from Swedish companies (that are a part of the European Emission Trading Scheme) in 2008 [2]. Therefore their ability to switch to renewable energy sources could contribute to mitigate climate change effects. Since a large part of Sweden is covered by forest or agricultural land, biomass has the potential to be one of these renewable sources.

Several studies have analysed the options for biomass use in Sweden [3; 4]. More specifically, the potential for increased biomass use and refining in the pulp and paper industry is analysed by e.g. Andersson [5]. Berntsson et al [6] and Johansson et al. [7] analyses the biomass use in the oil refining industry and Norgate and Landgate [8] investigates the same issue for the iron and steel industry. This study includes these three industries in order to get a comparative view on the potential for biomass use and refining in Swedish energy-intensive industry. However, it is important when studying these industries jointly to take into account their different prerequisites for use and refining of biomass, regarding current feedstock as well as processes. The aim of the study is to investigate how these industries can contribute towards a future increased use and refining of biomass. A case study approach is used and three case companies are studied, one for each industry. The aim of the study is evaluated through three research questions; 1) What are the possible technological options for increased use and refining of biomass for the studied industries? 2) If implemented in the case companies, what

amount of biomass would these technological options require compared to the potential of increased biomass supply in Sweden 2020? 3) What possibilities and obstacles do the case companies recognize for increased use and refining of biomass in their industry?

2. Methodology

This interdisciplinary study illuminates both technological options and business strategies, revealing conflicting and co-operational interests and creates the potential for a profound understanding of sustainable future development in this area. The study is based on a case study approach and both interviews and literature surveys are used to collect data. For research question 2 and 3 each industry is represented by a case company, which are presented at the end of this section. The case companies are chosen since they all have an ambitious attitude to climate change mitigation activities and have shown interests in collaborations with universities.

The first research question is answered by a literature survey, in which the following commercial technologies are included; pyrolysis, catalytic cracking, hydro cracking and production of wood-fuel pellets. Not commercially available technologies included are second generation ethanol fermentation, biomass gasification, lignin extraction and black liquor gasification.¹ Technologies in an early stage of development or with a limited potential to increase the use and refining of biomass in the industrial sectors were not included in this study. The included technologies are based on wood and agricultural biomass and do not compete with the core capabilities of the case companies. For the second research question the result of the first is combined with the different preconditions at the case companies and the potential future biomass demand. However, only technologies that are possible to implement at each case company are evaluated. The results for the third research question are based on qualitative and semi-structured interviews. Two representatives for each case company were interviewed, one at corporate group level and one at facility level.

In this study biomass is considered to be a limited resource. The biomass required to implement a technology is therefore compared to the future potential of increased biomass supply in Sweden. Several studies have estimated the increase in supply of wood and agricultural biomass, in Sweden. In this study a moderate increase of biomass supply has been used, estimated of 38 TWh/year in 2020 in reference [9].

The studied case companies are; Södra Cell for the pulp and paper industry, SSAB for the iron and steel industry and Preem AB for the oil refining industry. For the calculations in research question 2, the following specific facilities are used; Södra Cell Värö that produced 380 ktonnes of kraft pulp [10], SSAB Strip Products in Luleå that produced around 2.2 Mtonnes of steel slabs and 750 ktonnes of coke [11] and Preem's refineries in Lysekil and Gothenburg with annual oil refining capacities of 11.4 Mtonnes and 5 Mtonnes of crude oil respectively in 2008[12]. The choice of facilities limits the study to kraft pulp mills² for the pulp and paper industry and to integrated steel plants³ for the iron and steel industry. Additionally, the refinery in Gothenburg is smaller and less complex than the refinery in Lysekil.

¹ More information about these biorefining technologies can be found in Johansson et al [13].

² Chemical pulp and not paper is the final product.

³ The processes are based on iron ore.

3. Results

This section presents opportunities for increased use and refining of biomass in the three energy-intensive industries studied. Furthermore, the amount of biomass required for the options are related to the estimated increase in biomass supply in Sweden in 2020. Additionally, the case companies' views on future increased use of biomass in their industry are presented. To distinguish the results based on interview outcomes from results based on calculations or literature studies all interview references are marked with an asterisk.

3.1. Pulp and paper industry

For the pulp and paper industry, with its wood biomass based processes and extensive experience of logistics of timber, the increased demand for biomass has lead to increased competition for the industry's raw material but also opened new opportunities for increased refining of intermediate and by-products. The existing infrastructure for transportation of raw materials, storage possibilities on site and knowledge of handling of biomass can facilitate increased import of biomass as well as export of products based on biomass.

Like the industry in general, the case company Södra Cell is affected by the changes in its environment. The price of biomass, chemicals and energy affect the production cost, on the other hand energy prices also affect Södra Cell's incomes positively [14]*. Södra Cell's strategy is to increase energy efficiency in order to minimise purchased energy so that only raw material is bought and additionally the company wishes to become independent from fossil fuel [14]*. This is achieved by increasing the efficiency of the production processes, through technological choices adapted to the different prerequisites at Södra Cell's three Swedish mills. The mill in Mönsterås has invested in a condensing turbine to increase electricity production, Södra Cell Mörrum is planning a LignoBoost⁴ process and Värö's mill installed a bark drier during 2009. The company is interested in using new technologies for producing non-cellulose-based products, e.g. district heating, electricity, lignin or tall oil, but only as long as these are produced from residues and thus do not compete with pulp production [14]*. All these alternatives offer the possibility of increased export of energy products without increasing the total import of biomass to the facilities. Policies, particularly the green certificates for electricity, have contributed to justify activities that improve energy efficiency and investment in new technologies.

In the case of replacement of the recovery boiler or increase in production capacity in a kraft pulp mill, gasification of black liquor could be an interesting alternative. The technology is currently at the demonstration plant level and it is argued by Pettersson and Harvey that a large scale implementation is unlikely to occur before 2020 [15]. Their conclusions are based upon a study of energy and material balance consequences of implementation of black liquor gasification for production of DME in a model mill. They argue that pulp mills will be more energy efficient by 2020 (using best available technology of today). The study shows that one consequence would be an increased biomass demand that, in the case of Södra Cell Värö would correspond to about 700 GWh/year. Södra Cell claims that the main barrier for implementing this technology is the high investment cost of the gasifier [14]*. Ekbohm et al. [16] estimated the investment cost for a large scale gasifier to be more than twice the cost for a recovery boiler with the same capacity. Furthermore, the technology would also compete for biomass feedstock with the LignoBoost process [14]*. Finally, a sign of another path of development with a slightly different character is Södra Cell's research on green chemicals,

⁴ A process for separating lignin from black liquor. The lignin is sold as high value fuel.

which is conducted at the headquarters in Växjö by an R&D team of 50 peoples based in Värö [14]*.

3.2. Iron and steel industry

The spectrum of options to increase use and refining of biomass in an integrated steel plant is narrow, but the existing options have great potentials to reduce the industry's CO₂ emissions. An integrated steel plant can replace some of the coke used as reducing agent in the blast furnace, with biomass derived products such as charcoal, syngas, methane and ethanol. However, it is not possible to substitute all the coke in the blast furnace as coke acts as a physical support material and hence ensures correct gas permeability, process temperature and process drainage. Moreover, gasified biomass can be used as fuel in the steel plant's heating furnaces and replace the fossil fuel used today. Another option for an integrated steel plant is a partnership in an industrial symbiosis together with a biorefinery. For example, excess heat from the steel plant can be used by an ethanol plant and the ethanol can be used as reducing agent in the blast furnace or as transportation fuel in the steel plant's vehicles. Furthermore, an integrated steel plant can cooperate with a gasification plant and a Direct Reduced Iron (DRI) plant. The DRI plant can use syngas from the gasifier together with coke oven gas as reducing agent and DRI can be charged into the blast furnace or into the converter.

The interviewed representatives at the case company SSAB Strip Products state that a large scale replacement, of for example coke with products derived from biomass in the blast furnace, would need an extensive amount of biomass which makes it unlikely to be realized [17]*. Calculations for SSAB Strip Products demonstrate that a replacement of the pulverised injection coal with pulverised charcoal would demand approximately 4.4 TWh/year⁵ of dry wood. If instead bio-methane was considered for injection, it would be possible to replace one third of the injection coal without affecting the blast furnace process [17]*, which would demand approximately 1.5 TWh/year of methane. If the methane is produced through gasification of biomass it would demand about 2.5 TWh/year⁶ of dry wood. However, SSAB Strip Products identifies a risk in substituting coke with products derived from biomass as a substitution could affect the quality of the products, before the process is optimised, which could reduce the company's competitiveness [17]*.

The development of CO₂ prices and the global raw material markets will probably have the greatest impact on SSAB Strip Products' choice of future development path [17]*. Currently, energy-rich process gases are exported from SSAB Strip Products and used as fuel in a combined heat and power (CHP) plant. With regard to biomass use, the representatives from SSAB Strip Products consider it a better option to investigate possibilities to use excess energy-rich gases from the steel production internally at SSAB Strip Products and use biomass in a CHP plant [17]*. As a result of this line of reasoning, the company is increasing the efficiency of its energy system and aims at reducing its CO₂ emissions by 2% by 2012, which corresponds to 130,000 tonnes of CO₂ [11].

3.3. Oil refining industry

In a transition to more sustainable production and use of fuels the oil refining industry could play an important role with its extensive experience in processing and converting petroleum oil products into valuable fuels. The oil refining industry has the opportunity to use existing equipment for refining of biomass. By using the existing catalytic cracking unit or the

⁵ Calculations were based upon a biomass-carbonisation kiln with a weight-basis yield of 37%.

⁶ In the calculations, a gasification plant with a biomass to SNG conversion efficiency of 60% is used.

hydrotreating unit bio-oils can be upgraded to transport fuels that meet the existing fuel standards. At present, there is an increasing demand of hydrogen in the oil refining industry which is due to a process change into more valuable products, e.g. diesel, aviation fuel etc. This increasing demand can be supplied by production of hydrogen through gasification of biomass. Moreover, hydrogen could also be produced by natural gas steam reforming and indirect use of biomass via production of synthetic natural gas (SNG). Another option for utilisation of biomass in the oil refining industry is gasification followed by Fischer Tropsch synthesis. This process could be placed on-site at the refinery or off-site, closer to the biomass feedstock. To maximise the production of Fischer Tropsch diesel and improve the efficiency, the by-products from the process, naphtha and wax, could be further utilised in existing refinery processes.

Results from the interview with the case company for the oil refining industry, Preem AB, show that they consider biomass as a raw material that could be used in their processes, since this offers a new business opportunity and the company seems eager to be an early mover in the market for green diesel [18]*. On the other hand this can also be regarded as a matter of survival for Preem AB, since many European oil refineries of the same size as Preem AB's refinery in Gothenburg have faced bankruptcy lately [18]*. Preem's strategy for the future consists of two parallel paths: developing the Gothenburg refinery towards the production of green diesel and increasing the complexity of the Lysekil refinery for refining of crude oil [18]*. This strategy includes a recently started biomass-based hydrotreating process in Gothenburg, which is regarded as a step between the first and second generation renewable fuel, i.e. fuel production based on gasification. Karlsson and Nyström [18]* explain that regarding the development of gasification, they consider cleaning after the process as a huge challenge which demands co-operation by industry, universities and the government, in order to reduce risks and exchange competencies.

Calculations for Preem AB's refineries in Sweden show that replacement of the total hydrogen demand through gasification⁷ of solid biomass would demand approximately 1.2 TWh/year at Gothenburg refinery and 6.60 TWh/year at Lysekil refinery. However, if hydrogen is produced through gasification of pyrolysis oil, i.e. including a pyrolysis pre-treatment step for the biomass, biomass requirements of 1.7 TWh/year in Gothenburg and 9.2 TWh/year in Lysekil are needed. With regard to hydrogen production through steam reforming of SNG, supplying Preem's refineries in Gothenburg and Lysekil would require approximately 1.8 and 9.5 TWh/year biomass respectively. It is important to stress that these requirements are based on the current total hydrogen demand and on the assumption that it is possible to replace the whole demand. More detailed calculations about biomass gasification in Gothenburg are found in Johansson et al. [7].

The adjustment of the refinery in Lysekil for optimal use of crude oil, is motivated by the belief that there will continue to be a market for liquid fuel from crude oil, due to crude oil's efficiency as an energy carrier and its relative low cost [18]*. Since biomass is a limited resource Preem AB's plan is a 30% blend of green diesel into fossil diesel. Calculations show that the production of 100 000 m³ diesel, with a 30% renewable content, will at the refinery in Gothenburg demand 1.15 TWh/year of raw tall oil, requiring 55% of the total Swedish raw tall oil production. Although tall oil is the first biomass-based raw material Preem AB is investigating other options are for example used oils and oil from algae [18]*.

⁷ Calculations are based on assumptions presented in [13] and for gasification for hydrogen production updated with result from [7].

3.4. Future prospective

Even though current policies try to stimulate use of biomass as a source of energy and several technological options are possible, none of the case companies believes that biomass will increase significantly in the Swedish industrial energy system over a longer time perspective. The reason for this is that biomass is regarded as a limited resource and neither SSAB Strip Products nor Preem believe that biomass could represent a large-scale substitute for the currently used fossil fuel. The case companies' views on biomass as a limited resource are in line with the result that is obtained when calculating the biomass demand from the previous described technologies in comparison with the future increase in biomass supply in Sweden until 2020.

The biomass demand for the technological options that can be seen in Fig. 1 show a large share of the biomass considered to be available for new actors in 2020. However, it is important to note that the potential described above is the highest possible demand; some of the technologies may be implemented in a smaller scale, needing less biomass. Furthermore, it is not possible to implement all technologies described in section 3.1-3.3 in one facility within the case company at the same time as some of them compete for the same resources or supply the same feedstock.

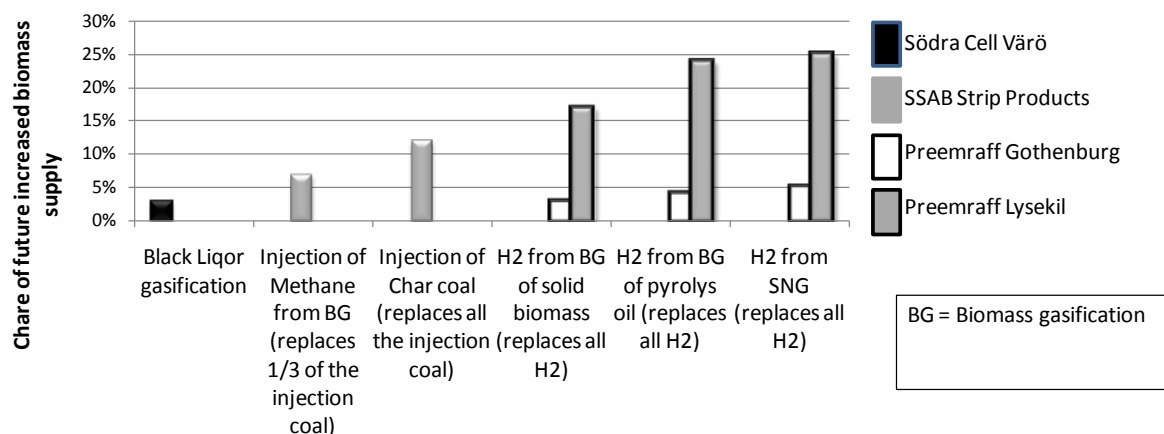


Fig. 1. The share of future increase in biomass supply that is needed if a technology to increase biomass use/refining would be implemented at each case company. Note that this is the highest biomass demand. Options not requiring increased import of biomass or do not significantly affecting the CO₂ balance at the case company are not included.

Adding the biomass demand for hydrogen production from biomass gasification at Preemraff Lysekil and Gothenburg, injection of pulverised charcoal at SSAB Strip Products and black liquor gasification at Södra Cell Värö would require 34 % of the total increase of biomass supply in 2020 (38 TWh/year [9]). For the pulp and paper industry the only option that requires increased import of biomass is included, in the oil-refining industry the hydrogen production alternative with the most efficient use of biomass is included and for the iron and steel industry the option substituting the largest amount of fossil fuel is included.

Despite the somewhat pessimistic view of biomass potential as a future feedstock the representatives we met at both Södra and Preem appreciate that the companies they represent have chosen to become actively involved in environmental issues. In a longer perspective, Södra hopes that they still can use biomass for their current core business, pulp production,

and additionally for production of e.g. composite material, cloths, chemicals or medicine [14]*. SSAB Strip Products does not believe that any biomass technology will be implemented at their facility. Instead they believe that available excess heat will be integrated with surrounding energy systems, in which biomass could be one of several feedstocks [17]*. In contrast, Preem's strategy for the refinery in Gothenburg to remain competitive is to modify existing infrastructure for production of both renewable and fossil diesel. Preem fears that competition for biomass as a feedstock between different industrial sectors will be more important in a longer perspective than competition within the oil refining industry [18]*.

4. Discussion and Conclusions

The study shows several possibilities for increased use and refining of biomass in the three industries studied: Kraft pulp mills can export by-products either unrefined or refined into higher value added products. Additionally, oil refineries can import biomass feedstocks for the production of green diesel or hydrogen and integrated steel plants can use biomass-derived products as reducing agent in the blast furnace. Finally, all three industries have options to export excess heat to biorefineries with demand for heat.

This study shows that technologies for increased use and refining of biomass implemented at three energy-intensive industries would require up to 34% of the Swedish potential for increased supply of biomass in 2020. Although estimations of the increase in biomass supply is very uncertain, the fact that biomass is a limited resource have been recognized by the case companies. Hence, it is important to evaluate the options in relation to alternative scopes of use for the biomass before any new investments are made. One important issue to address is how the biomass is most efficiently used in order to reduce CO₂ emissions. Furthermore, the market for biomass is global and biomass price and expected profits for the purchaser will probably have an impact on where the biomass will be used in the future. There are large differences in required amounts of biomass for the different industry sectors, which could affect the probability of realization of the options. Companies located near harbours may have a financial advantage on the global biomass market since transportation costs can be reduced. Finally, it is vital from an environmental point of view that the biomass resources are exploited in a sustainable way with re-planting and responsible land-use.

Regarding the case companies, both Södra Cell and Preem are investigating possibilities to introduce new technologies for increased use and refining of biomass and have identified this as a new business opportunity. On the other hand, SSAB Strip Products considers biomass a too limited resource, especially compared to coal and coke, which the company uses today, and is not interested in investing in facilities not related to its core capabilities. The interview results for Södra and SSAB Strip Products are in line with the results from the calculations. For Preem, the calculations indicate that a large amount of biomass would be required for the different options (see Fig 1), which would constitute a barrier for implementation. In the interviews the company has an optimistic view on implementing options for increased use and refining of biomass. However, these options are based on using existing infrastructure but adopting it to biomass based feedstock and are thus not the same technologies as in our calculations.

This study concludes that opportunities for Swedish energy-intensive industry to increase use and refining of biomass exist, but with many potential barriers for implementation. However, the study points towards a trend in Swedish energy-intensive industries; the industries are more aware of their CO₂ emissions and seek options to be more climate neutral.

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